Propagation and Throughput Study for 802.16 Broadband Wireless Systems at 5.8 GHz

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Abstract— This paper presents propagation studies and analyses of OFDM signals, following the 802.16-2004 standard, at 5.8GHz. Throughput measurements are conducted first in a controlled faded multipath environment in the lab, then in a suburban area. Results are analyzed and compared.

Index Terms—SUI propagation models, fading channels, OFDM.

I. INTRODUCTION

THIS paper presents the results of a study measuring data throughput of an OFDM radio system through various fade models. The radio system is 802.16-2004 compliant [1], using 256 FFT at 5.8 GHz. Only one sector is used, therefore no other cell interferences are considered. A single 20MHz channel is used for the sector and multiple access is obtained by time slot allocation to all units within the sector.

The first part of the paper presents a study of this system through a controlled environment, where radio multipaths and their resulting fades are generated by a channel emulator. The fading models are based on Stanford University Interim (SUI) channel models.

The second part of the paper presents the same radio system tested for throughput in a suburban area in Denver. In that case radio interferences are verified to remain consistent and fairly minimal in order to focus on channel variations similar to those considered in the controlled environment.

II. LAB TESTING

A. Test Setup

The radio system under test comprises one base station sector (BS) and several subscriber units (SU's). This study is interested in fixed broadband wireless communications in various propagation environments; consequently fixed models are considered, rather than the usual mobile propagation models. Tests were conducted to measure the throughput in different modulations. Devices were tested in a part cabled environment and part unbounded media as shown below. The cabled environment undergoes different fading channels programmed in a fading emulator. The air interface is a short direct line of sight with the BS and the SU's at a distance of 10 feet. This is done in order to couple signals of four SU's over the air onto one sector.

The Fading emulator allows us to emulate two separate channels, each comprised of several multipaths, each of which is independently faded and delayed. Fade statistics for the direct path are either Rayleigh or Ricean, fade statistics for the delayed paths are all Rayleigh. Finally additive white Gaussian noise is added to the overall channel (C/I=30dB).

As in many wireless LAN devices, our radio devices are TDD and have duplex ports: transmit and received signals go to one unique antenna. In our test, the fading emulator fades the transmit and receive paths independently, the two paths are therefore separated by circulators. Finally the fading emulator required some careful calibrating of power levels (especially due to the high peak to average ratio of OFDM signals). Radio transmit power levels were adjusted and additional attenuation (pad) was added where necessary. Figure 1 shows the detailed setup.
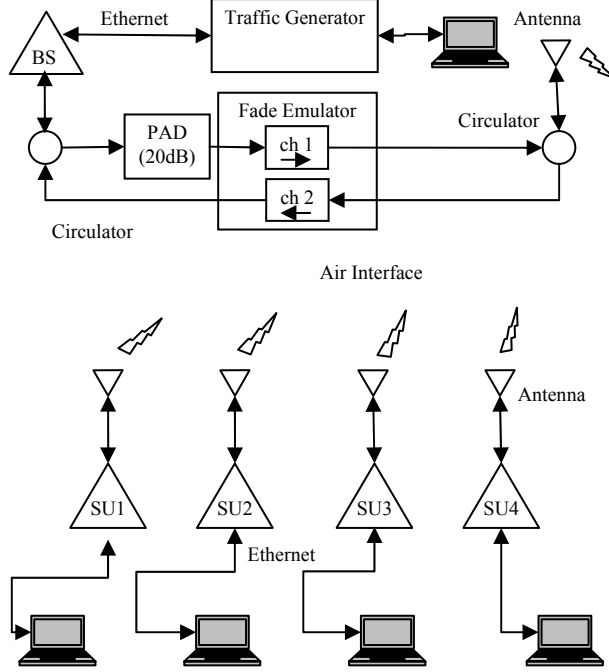
Fig. 1. Test Setup.

B. Channel Models

Different channel models are emulated using the modified Stanford University Interim (SUI) channel models. In particular we focus on fixed access and consider SUI-1, 3, and 5, described in table I below (SUI-4 & 6 have high Doppler spread and are not relevant to our study. Sui-2 is fairly similar to SUI-1). We therefore have a model for different terrain types A, B, and C, as described below (for more details, see [2], [3]).

TABLE I
FADING CHANNEL MODELS

Model	SUI-1	SUI-3	SUI-5
Terrain Type	A: Flat, light tree density	B: Hilly, light tree density or Flat, moderate heavy tree density	C: Hilly, moderate to heav tree density
Doppler	Low	Low	Low
Delay spread	Low	Low	High
Ricean K of direct path	4 (High)	1 (Low)	0 (Rayleigh)
Multi-path (delay & atten.)	3 paths, 1: direct 2: 0.4μs, -21dB 3: 0.9μs, -30dB	3 paths, 1: direct 2: 0.4μs, -11dB 3: 0.9μs, -22dB	3 paths, 1: direct 2: 14μs, -11dB 3: 20μs, -22dB

Throughput results are measured for these different SUI models and different modulations and coding: BPSK, QPSK and 16QAM, with forward error correction coding (convolutional coding) with a coding rate of 1/2, 2/3, or 3/4. (Tests were also conducted at 64QAM, but that throughput was perturbed by other system limitations rather tan propagation fading; and these results are therefore not meaningful.)

C. Results

Overall throughput is very steady and reliable with – as expected – increasing degradation as the index *n* of the SUI model (SUI-*n*). In BPSK, the SUI model has barely any impact on throughput, at higher modulations, a slight degradation is noticeable.
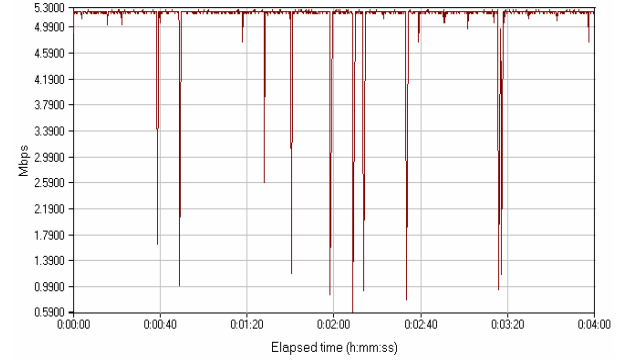

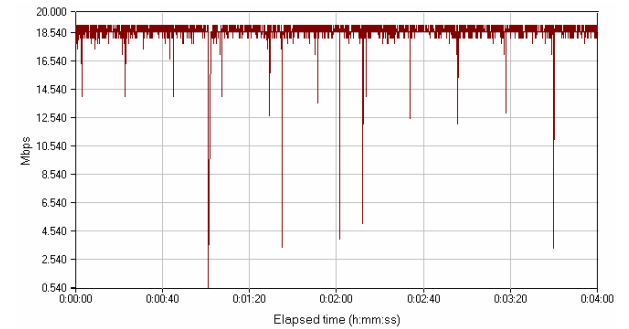Fig. 2. Throughput vs. time for BPSK modulation in SUI-1 channel model.

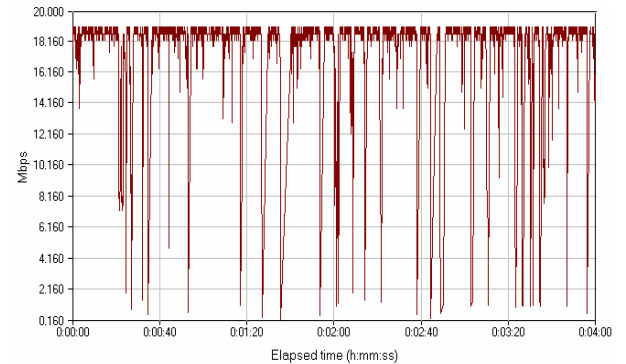Fig. 3. Throughput vs. time for 16 QAM modulation in SUI-1 channel model.

Fig. 4. Throughput vs. time for 16 QAM modulation in SUI-3 channel model.

Probability analysis of the throughput levels show a

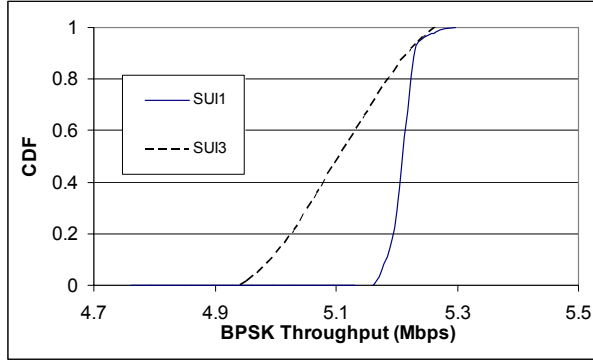very steep cumulative distribution function for SUI-1, less so for higher models.

Fig. 5. Cumulative distribution of throughput in BPSK modulation, for SUI-1 and SUI-3.
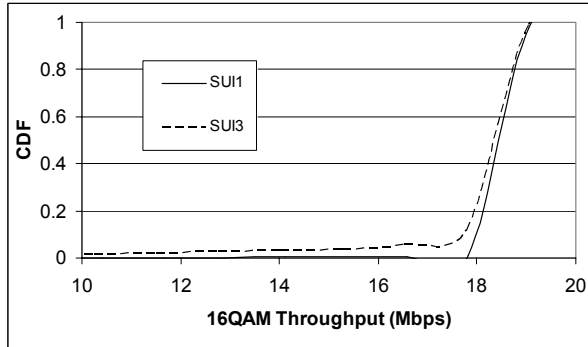

Fig. 6. Cumulative distribution of throughput in 16 QAM modulation, for SUI-1 and SUI-3.

Still, in spite of these differences, average throughput comparison shows no significant degradation as modulation increases. Our three SUI models are represented on Figure 5 and 6 and compared to the "bypass" setup which is simply cabled through the fade emulator in bypass mode.
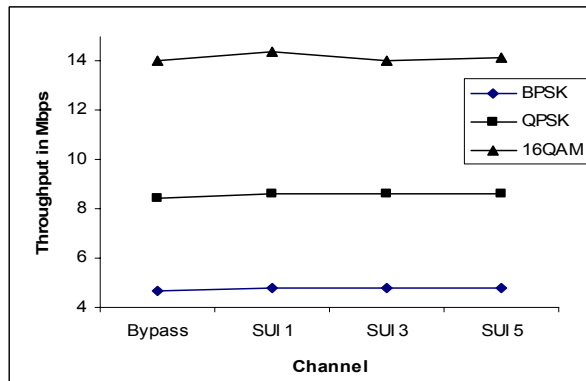

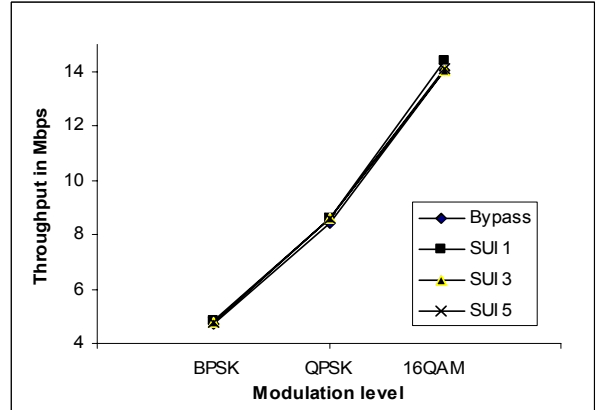Fig. 7. Average throughput in Mbps for various channel models at different radio signal modulations.

Fig. 8. Average throughput in Mbps for various channel models at different radio signal modulations.

D. Comments

The difference in propagation models does not significantly impact average throughput. Different SUI models present significant differences in fading, and these differences in fading statistics were observed; but the various coding schemes of an 802.16 radio system deal with these fades efficiently.

A further aspect that should be tested in future experiments is the impact of S/N or signal strength in those various SUI models.

III. URBAN TESTING

A. Test Setup

After the lab study we take the same equipment and conduct true field testing in a suburban area in Denver. The equipment used is similar than that of section I and Figure 1, but the circulators, padding and fade emulator are removed. The BS is placed on top of a 13-floor-high building, and the SU's are placed 6 to 8 feet off the ground, each on a small pedestal atop a vehicle roof.

In this case the system is configured differently from the lab setup in one important aspect: a modulation on demand is allowed where each SU is allowed to choose a specific modulation according to its SNR. Unlike the lab test, the BS is communicating with SU's at different modulations.

B. Single Unit

We first test throughput with one single SU at various locations within the sector. All locations are in obstructed line of sight, some only by minor foliage, some completely shadowed by buildings. In many cases insufficient signal was obtained to establish data link

reliably, these cases are not plotted but should be kept in mind: although our data points are very impressive for obstructed links at 5.8GHz, service is not ubiquitous.

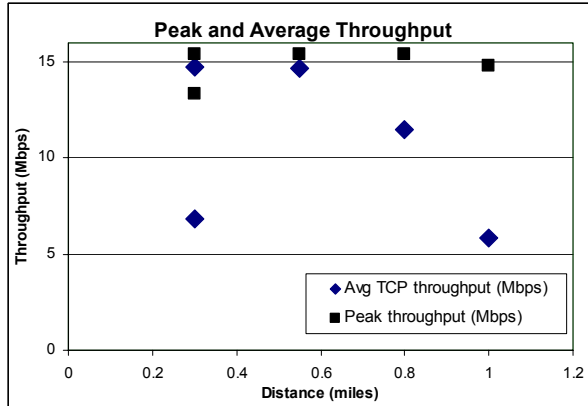**Peak and Average Throughput**

Fig. 9.   Average and peak throughput in Mbps for various locations within a sector in actual field testing.

To compare to lab experiment, we represent the cumulative distribution of all data points.
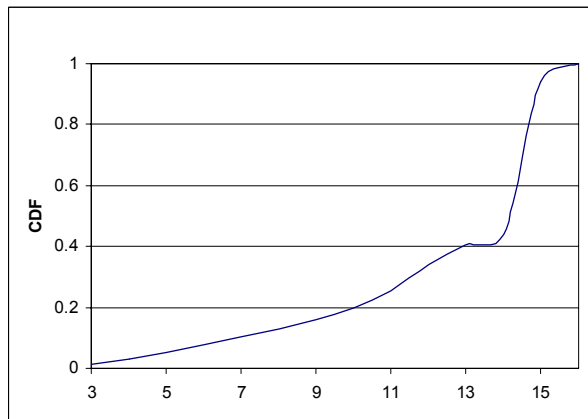

Fig. 10.   Cumulative distribution of throughput in various locations measured in a suburban area.

C. Multiple Units

Finally for practical considerations of several simultaneous users, we then test throughput with several SU's at various locations within the sector. All locations are again in obstructed line of sight, some only by minor foliage, some completely shadowed by buildings.

Three sets of measurements are collected, with three

to five SU's in different areas (represented by a contour on the map). In each contour donut-shaped symbols represent the location of the SU. A map representing the topography of the setup is shown at the end of the paper.
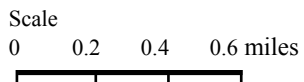
D. Comments

Throughput with one SU in different locations throughout the sector show good results in spite of obstacles such as trees, homes and urban traffic. When Several SU's are combined in one sector, details of the scheduling algorithm between SU's prevent us from analyzing these data point in too many details; but we nevertheless verified that performance is maintained when several SU's are used within one base station sector.

IV. CONCLUSION

We presented throughput measurements in three different SUI models for use in fixed broadband wireless access for rural and suburban areas. We then tested the system in a Denver suburb and observed similar throughput where signal strength was sufficient. Field tests reminded us that shadowing and obstruction effects are the most important point for any broadband radio deployment.

REFERENCES

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[2] IEEE 802.16 Broadband Wireless Access Working Group, "Channel Models for Fixed Wireless Applications" Contribution to 802.16a, 2003, available at http://wirelessman.org/tga/docs/80216a-03_01.pdf.
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[5] C. Chrysanthou, H. Bertoni, "Variability of Sector Averaged Signals for UHF Propagation in Cities," IEEE Trans. Vehic. Tech., Vol. 39, No. 4, November 1990, pp. 352-358.H.Suzuki: "A Statistical Model for Urban Radio Propagation" IEEE Trans. Comm,Vol.COM-25, No. 7, July 1977, pp. 673-680.

Scale

0   0.2   0.4   0.6 miles